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This report summarizes the results of our study on two methods for implementing smart material structures which can detect and reject high-power laser radiation over a broad spectrum. Our approaches are based on nonlinear photonic bandgap structures. The first approach is a multilayer system made up of alternating thin films with high and low nonlinearity. The second approach uses nonlinear optical colloids. It was found that the performance of the first approach does not achieve the designed level, because of the lack of suitable nonlinear materials. The second approach exhibits very promising results for rejecting high power laser radiation over a broad wavelength range, while maintains a good transparency at low radiation. Experimental evaluation of the second approach is presented.

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SMART MATERIAL STRUCTURES USING NONLINEAR PHOTONIC BANDGAP AND PHOTON LOCALIZATION FOR REJECTING HIGH-INTENSITY LASER RADIATION

FINAL REPORT

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Abstract

This report summarizes the results of our study on two methods for implementing smart material structures which can detect and reject high-power laser radiation over a broad spectrum. Our approaches are based on nonlinear photonic bandgap structures. The first approach is a multilayer system made up of alternating thin films with high and low nonlinearity. The second approach uses nonlinear optical colloids. It was found that the performance of the first approach does not achieve the designed level, because of the lack of suitable nonlinear materials. The second approach exhibits very promising results for rejecting high power laser radiation over a broad wavelength range, while maintains a good transparency at low radiation. Experimental evaluation of the second approach is presented.

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4. Technical Report

A. Statement of the Problem Studied:

Sensor and vision protection against high-intensity laser beams is very important in military applications. It is highly desirable to design a protection system or device which can sense high-intensity radiation and control its transmittance, to block harmful radiation. Such a system should possess sub-nanosecond response time and millisecond recovery speed, and reject high-intensity radiation over a broad wavelength range (from UV to IR). The system should also be transparent to low-intensity radiation in visible wavelengths, for human vision purposes.

We have studied nonlinear photonic bandgap structures for implementing novel protection devices. Our approaches are based on the principles of photonic bandgap structures [1-2] and nonlinear optics. Two systems are investigated. The first system (designated as the "thin-film system", shown in Fig. 1) is made up of alternating high- and low-nonlinearity materials with similar linear refractive indices and various layer thicknesses. The second system (designated as the "colloidal system", shown in Fig. 2) consists of nonlinear colloids with glass particles suspended in a nonlinear liquid mixture of CS_2, CCl_4, and $CHCl_3$. In Figs. 1 and 2, n_H represents the refractive index of layers with high optical nonlinearity and is given by

$$n_H = n_0 + n_2 I$$

where n_0 is the linear refractive index, n_2 is the nonlinear index coefficient, and I is the light intensity. n_L represents layers with low nonlinearity, chosen to be almost equal to n_0. When I is very small, $n_H = n_L$ and the whole system behaves as a uniform transparent medium. When I

is high, however, n_H is different from n_L and the systems have non-uniform refractive index which causes photon scattering or localization, and high loss for the incident radiations. Numerical analyses [3-5] have showed that both systems are very effective in rejecting high-intensity radiation over a broad spectrum. Our research focused on the design, implementation, and experimental evaluation of these systems.

We have attempted to solve the following problems:

A. The thin-film system: The main problems are (1) difficulty to deposit many layer of films, and (2) lack of suitable nonlinear materials.

B. The colloidal system: The main problem is to have a good mixture of the nonlinear liquid with good transparency for low light intensity and strong scattering for high light intensity over a broad spectrum.

B. Summary of the Most Important Results

1. The thin film system:

We attempted to implement the system using polymeric Langmuir-Blodgett films. Our focuses have been on growing good films with large number of layers. The number of layers increased significantly when we minimized the structural defects. We have optimized deposition conditions for best film uniformity of each layer, eliminating striation parallel to the water meniscus during dipping, and maximizing film adhesion. As a results, we have grown L-B films with hundreds layers up to hundreds for various linear materials. Alternative layers of linear and nonlinear materials are also grown. Table I list some of the materials tested in this study.

In addition to those in Table 1, several other materials have been used for depositing L-B polymeric films. We have successfully deposited multilayer L-B films using the following nonlinear optical materials:

1. New Conjugate polymers: Poly(arylenevinylene) and Poly(arylenes)
2. D85N mutant bacteriorhodopsin
3. PMMA doped with Rhodamin 575
4. Liquid crystal E7

These L-B films have very good optical properties (uniformity and transparency).

The nonlinearity of these films were measured using the Z-scan method and four-wave mixing. Although the samples showed interesting nonlinear behaviors in the Z-scan measurements, the nonlinearity is still not high enough for optical power limiting.

The lack of materials with high optical nonlinearity have forced us to look into other approaches for implementing photonic bandgap structures and optical power limiters.

2. The colloidal system.

We have investigated several methods to implement the colloidal system as shown in Fig. 2. Good samples were prepared using a novel technique developed in our laboratory. The samples consist of glass particles suspended in a nonlinear liquid mixture of CS2, CCl4, and Ch3Cl4. Details of the technique for preparing the samples are described in the document of a pending US patent.

The measured results of the colloidal samples indicate good performance of these systems. Fig. 3 shows the absorption spectrum of a sample. It is seen that the linear transparency is around 60% at visible wavelengths. Fig. 4 and 5 show the optical limiting capability of the sample at two different wavelengths.

The input laser was from a tunable dye laser with a pulse width of 10 ns. With 7 mm aperture, the transmittance of the system at high intensity is around 10%. A smaller transmittance (5%) was obtained for smaller apertures (4 mm), as shown in Fig. 4.

It should be noted that the tested sample is one of the first ones prepared in this study. With further optimization in the sample fabrication, we expect much better performance. We believe that the colloidal system is a promising candidate for optical power limiting applications.

C. Publications:

1.Y. Zhao, D. Huang, C. Wu, and R. Shen, "Comparative study of one-dimensional photonic bandgap structures using multilayer nonlinear thin films," J. Nonl. Opt. Phys. and Mat., 4, 1-11, (1995).

2. Y. Zhao, D. Huang, R. Shen, and J. Xu, "Implemention of smart photonic bandgap structures using Langmuir-Blodgett films," in Smart Materials, A. P. Jardine, Ed., SPIE-Proceedings 2441, (1995).

D. Scientific Personnel

Principal Investigator (1)	Yang Zhao
Postdoctoral Research Associate (1)	Dan Huang (now at Air Force Philips Lab)
Graduate Assistants (4)	Jie Lu (MS degree completed) Krishnan Narayan (MS completed) Ping Yin (PhD in progress) Zining Fu (MS, non-thesis, completed)

5. Inventions

Broad band optical power limiter using nonlinear optical colloids (US Patent pending).

6. Bibliography:

1. C. M. Soukoulis "Photonic band gaps and localization" Plenum Press, New York, (1993)

2. Henry O. Everitt, "Applications of Photonic Band Gap Structures," Optics & Photonics News, 20-23, Nov. (1992).

3. K. M. Yoo and R.R. Alfano, "Broad bandwidth mirror with random layer thicknesses," Appl. Opt., 28, 2456-2458, (1989).

4. Y. Zhao, D. Huang, C. Wu, and R. Shen, "Comparative study of one-dimensional photonic bandgap structures using multilayer nonlinear thin films," J. Nonl. Opt. Phys. and Mat., 4, 1-11, (1995).

5. C. J. Herbert, et al., "Optical Power limiting with nonlinear periodic structures," Opt. Lett., 17, 1037 (1992).

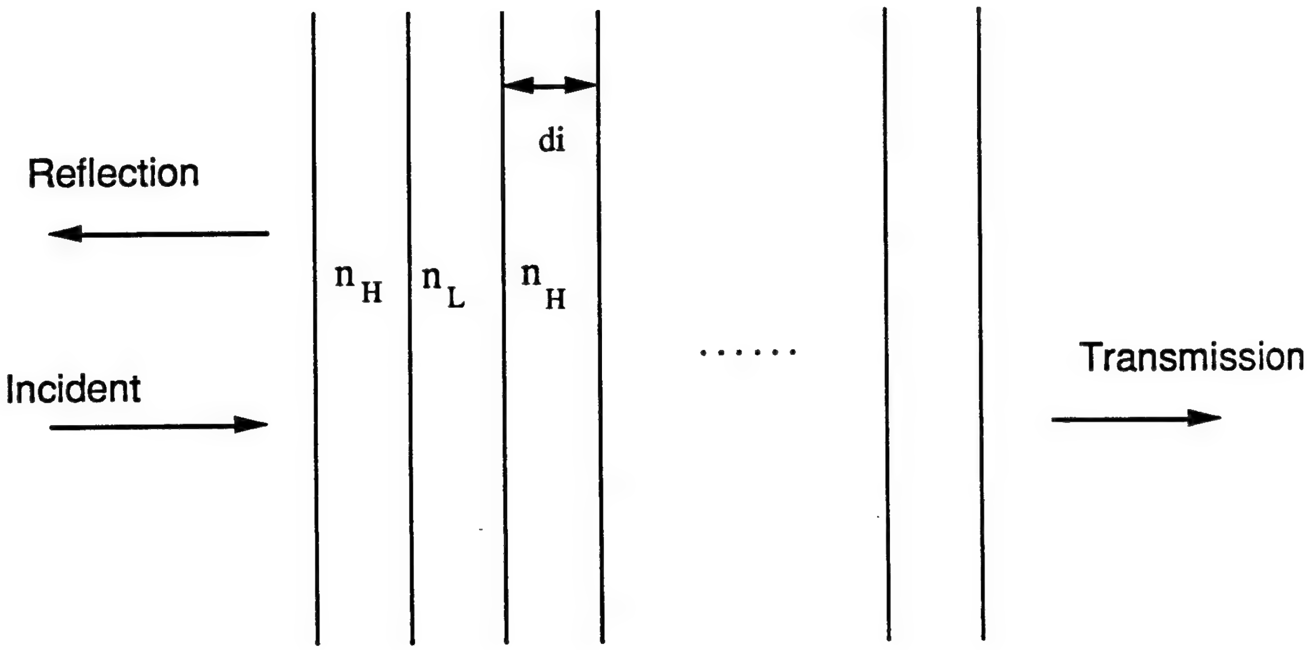

Fig. 1. Multilayers of optical thin films with high- and low- nonlinearity

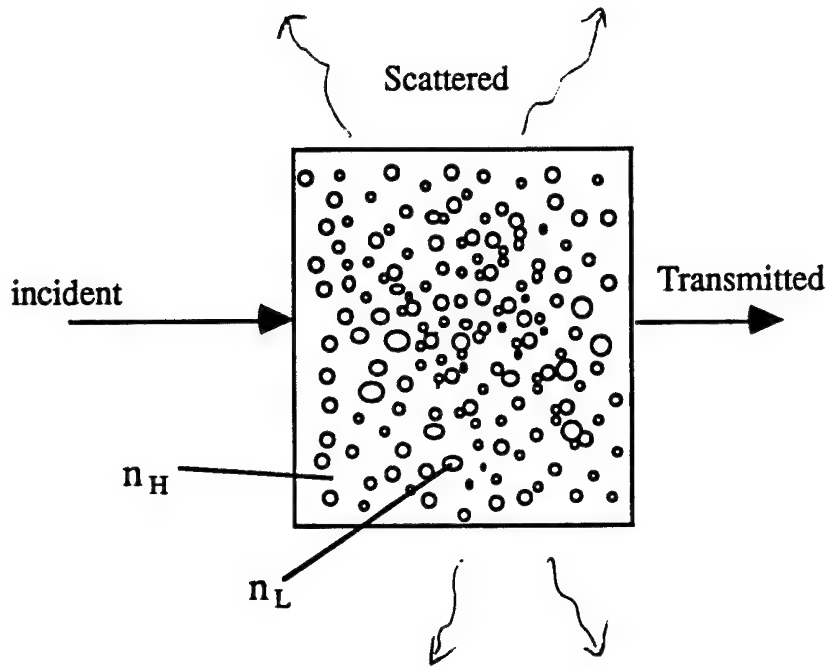

Fig. 2. Nonlinear optical colloids

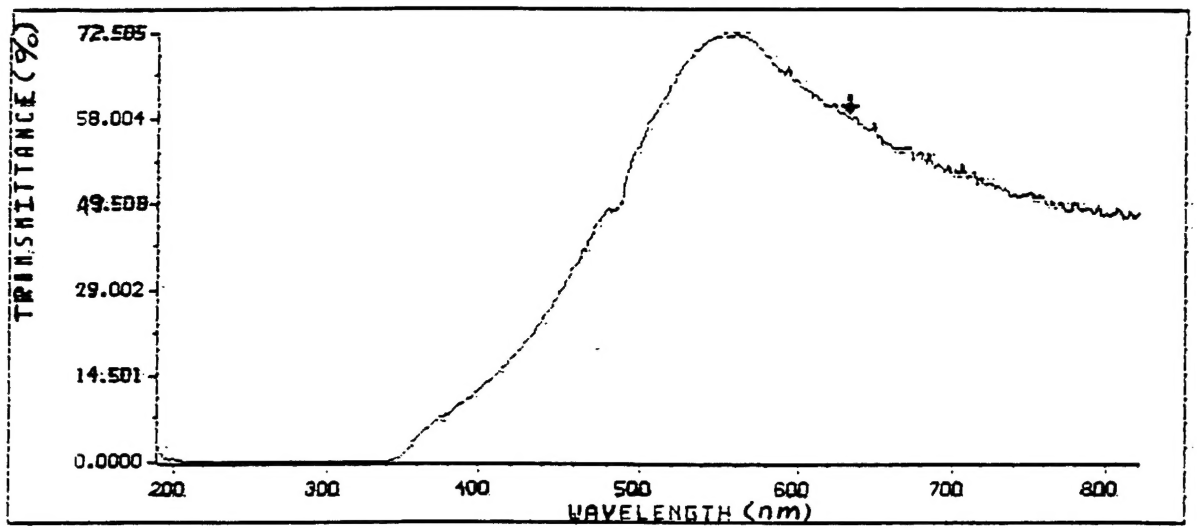

Fig. 3. Linear absopriton spectrum of the colloid sample.

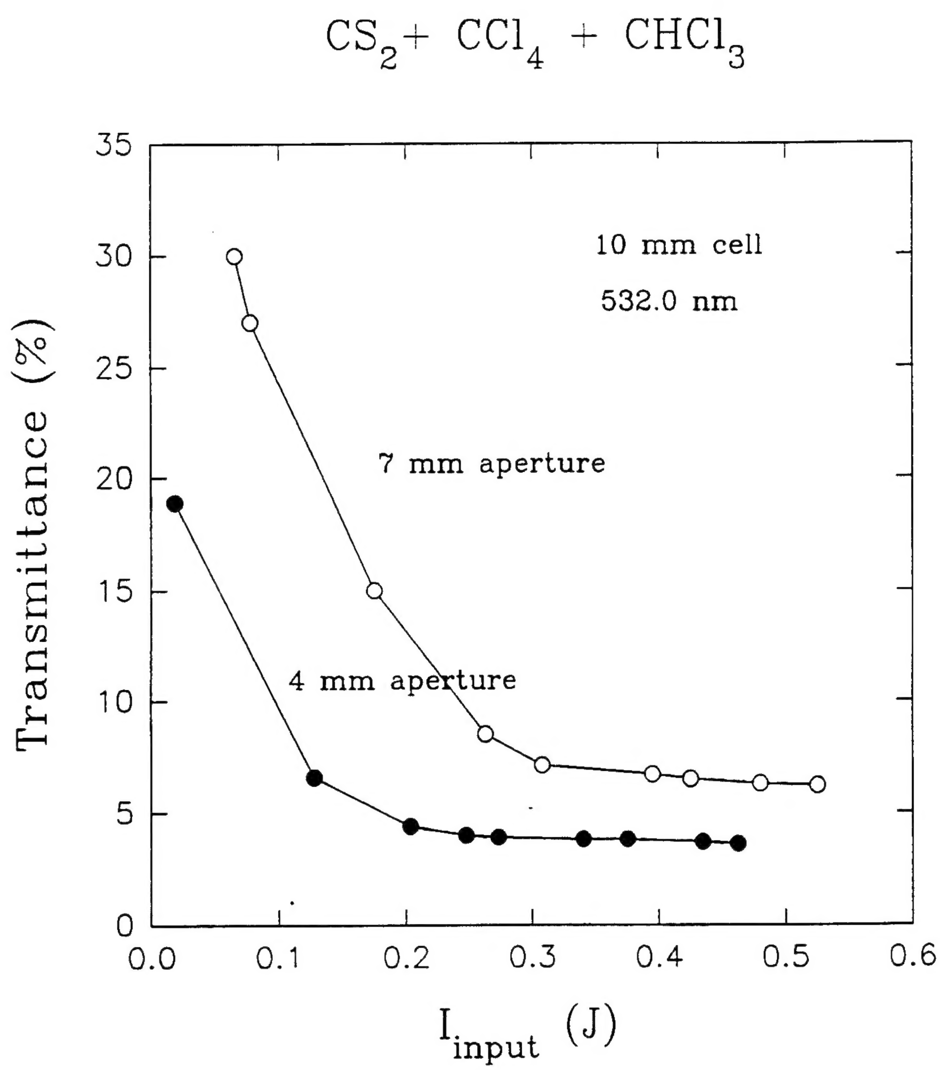

Fig. 4. Optical limiting of the colloid sample at 532 nm

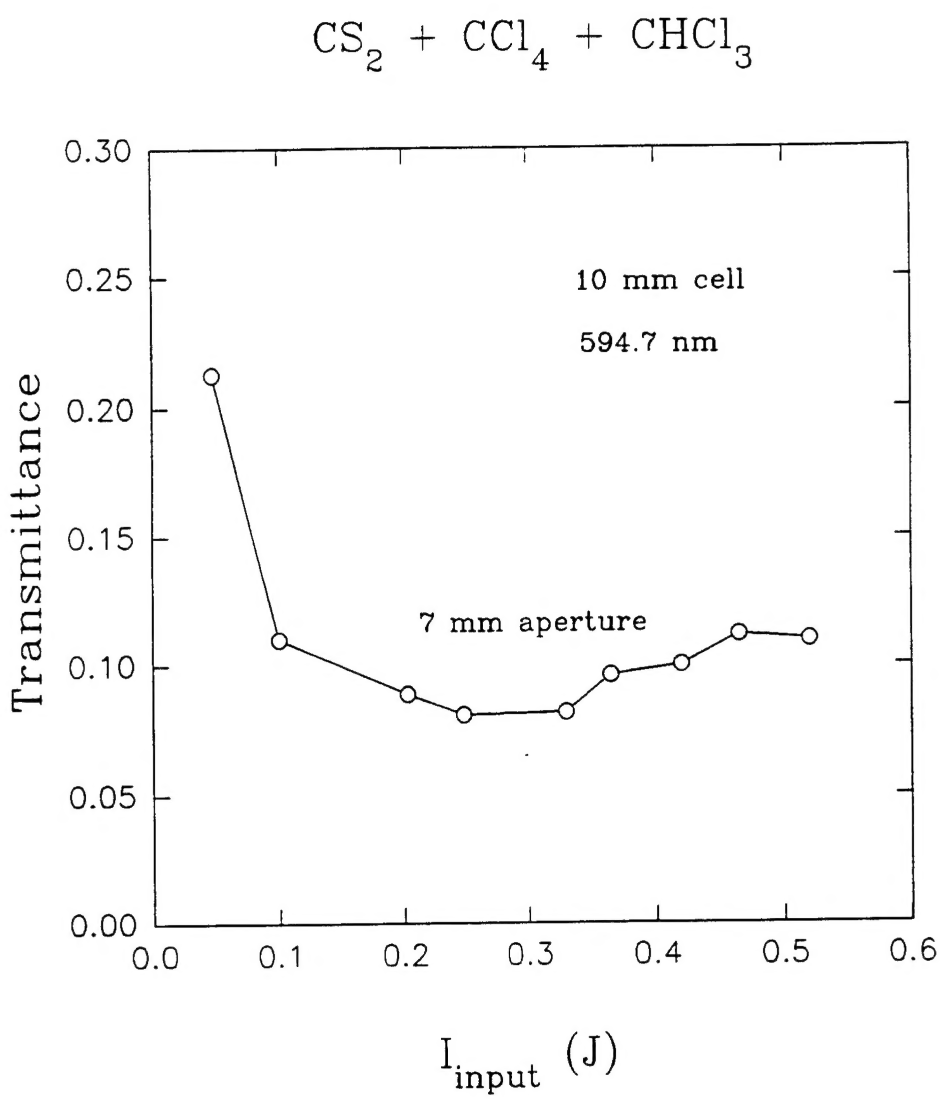

Fig. 5. Optical limiting of the colloid sample at 595 nm

Table 1. Summary of Langmuir-Blodgett films prepared during this study.

No	Sample	Layers	Pressure (mN/m)	Speed (mm/min)	Type
1	p-phenylphenol	4	4	2	Z
2	p-phenylphenol	8	8	5	Z
3	Polybenzidine	4	15	2	Z
4	Polybenzidine	10	12	5	Z
5	Polybenzidine	22	10	5	Z
6	Copolybenzidine	20	12	5	Z
7	Poly1/Stearic acid	3/3	10/10	3	Z
8	Poly/Stearic acid	5/5	8/8	5	Z
9	Ma-I-96	30	15	5	Y
10	Ma-I-96	40	10	5	Y
11	Ma-I-96	3	12	3	Z
12	Hu-I-76-1	10	1	5	Z
13	C_{20}	1	15	5	Z
14	C_{60}	1	10	5	Z
15	C_{60}	5	8	5	Z